GRAPHIC CLOSURE INDICATOR FOR COCKPIT TRAFFIC DISPLAY

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application Serial No. 60/243,239, filed October 25, 2000.

TECHNICAL FIELD

This invention relates to displays of traffic in the cockpit of an aircraft and, more particularly, relates to displaying an indication of closure between an Own Ship aircraft and a selected target aircraft in response to the flight characteristics of the selected target aircraft satisfying certain specified criteria.

BACKGROUND OF THE INVENTION

A primary task for pilots is to be aware of nearby air traffic by maintaining a constant visual scan. If traffic is sighted, the pilot must first assess the threat posed by the intruder aircraft, then, if necessary, maneuver to avoid the aircraft. This strategy is termed "see-and-avoid." The effectiveness of see-and-avoid depends on the ability of a pilot to visually acquire an intruder aircraft early enough in the encounter to enable threat assessment and avoidance. A Cockpit Display of Traffic Information (CDTI) assists the pilot with see-and-avoid by providing a display of nearby traffic.

A CDTI display typically displays nearby target aircraft and information about the target aircraft, such as altitude, track, and identification information. This information may be received from one or more sources, including Traffic Information Service (TIS) from a ground-based air traffic control center, and Automatic Dependent Surveillance-Broadcast (ADS-B) from transponders on other aircraft, or vehicles

The ability to easily determine from the display the movement of nearby aircraft relative to the aircraft containing the display is especially desirable for effective threat assessment and avoidance. Additionally, aircraft operations can benefit from the timely and effective presentation of traffic information that can assist in decision making for the flight crew. Thus, there is a need for enhancements to CDTI units to provide easily-readable graphic indications of the relative movement and status of nearby aircraft.

SUMMARY OF THE INVENTION

The present invention is an improvement in displaying traffic information on an aircraft display, such as a CDTI. More specifically, the invention provides a method and system for graphically displaying on a cockpit display a graphical indication of the rate at which an Own Ship aircraft is closing in on, or receding from, a selected target aircraft. This rate, which is generally referred to as a "closure rate", has a positive value if the Own Ship aircraft is closing in on the selected target aircraft, and a negative value if the Own Ship aircraft is receding from the selected target aircraft. The graphical indication of the rate at which the Own Ship aircraft is closing in on, or receding from, the selected target aircraft is generally referred to as a "closure indicator."

In a preferred embodiment of the invention, the system displays a closure indicator in response, at least in part, to both of the following requirements being satisfied: (1) the selected target aircraft is within a pre-determined monitoring zone; and (2) the track of the selected target aircraft is within a pre-determined variation angle of the track of the Own Ship aircraft. In an alternative embodiment of the invention, the system also displays the closure indicator, at least in part, in response to (3) the rate of closure between the selected target aircraft and the Own Ship aircraft being within a predetermined range of values. In a preferred embodiment of the invention, the system is

configured to display no closure indicator, at least partially in response to the system failing to meet one or more of the above requirements.

As noted above, a system according to a preferred embodiment of the invention only displays a closure indicator if the first two of the above requirements are satisfied. However, in various alternative embodiments of the invention, the system is configured to display a closure indicator only if a different pre-determined two of the above requirements are satisfied. For example, in one embodiment of the invention, the system only displays a closure indicator if requirements 1 and 3, above, are satisfied. Such a system only displays a closure indicator if: (1) the selected target aircraft is within a pre-determined monitoring zone; and (2) the rate of closure between the selected target aircraft and the Own Ship aircraft is within a predetermined range of values. In another embodiment of the invention, the system only displays a closure indicator if requirements 2 and 3, above, are satisfied. Such a system only displays a closure indicator if: (1) the track of the selected target aircraft is within a pre-determined variation angle of the track of the Own Ship aircraft, and (2) the rate of closure between the selected target aircraft and the Own Ship aircraft is within a predetermined range of values.

In another alternative embodiment of the invention, the system only displays a closure indicator if each of requirements 1-3 is satisfied. Such a system only displays a closure indicator if: (1) the selected target aircraft is within a pre-determined monitoring zone; (2) the track of the selected target aircraft is within a pre-determined variation angle of the track of the Own Ship aircraft; and (3) the rate of closure between the selected target aircraft and the Own Ship aircraft is within a predetermined range of values.

In a further alternative embodiment of the invention, the system displays a closure indicator if a pre-determined one of the above requirements is satisfied. In an additional alternative embodiment of the invention, the system constantly displays a closure indicator on the display screen while the aircraft is in flight.

The system is preferably configured to remove a closure indicator from display on the display screen in response to either the Own Ship aircraft landing or the selected target aircraft landing.

In a preferred embodiment of the invention, the pre-determined monitoring zone referenced above is positioned adjacent to a front portion of the Own Ship aircraft. This

pre-determined monitoring zone is preferably a substantially cone-shaped segment of airspace. Additionally, the cone-shaped segment of airspace is preferably positioned so that the apex of the cone-shaped segment of airspace is adjacent a front portion of the Own Ship aircraft. Furthermore, the cone-shaped segment of airspace is preferably oriented so that the axis of the cone-shaped segment of airspace is substantially co-linear with the track of the Own Ship aircraft. In one embodiment of the invention, the apex of the cone-shaped segment of airspace is immediately adjacent a front portion of the Own Ship aircraft and the axis of the cone-shaped segment of airspace is oriented in substantially the same direction as the track of the Own Ship aircraft. The vertex angle of the cone-shaped segment of airspace is preferably about 40 degrees. In a preferred embodiment of the invention, the system is configured for allowing a user to at least partially modify at least one boundary of the monitoring zone.

Turning now to the requirement that the track of the selected target aircraft be within a predetermined variation angle of the Own Ship aircraft's track, the predetermined variation angle is preferably about 20 degrees. In a preferred embodiment of the invention, the system is configured to allow a pilot or other user to modify the pre-determined variation angle to account for current flying conditions.

The closure indicator displayed by the system preferably comprises an alphanumeric value indicating the current rate at which the Own Ship aircraft is closing in on, or receding from, the selected target aircraft. The closure indicator also preferably includes a plus or minus sign immediately adjacent to the alphanumeric value to indicate whether the Own Ship aircraft is closing in on, or receding from, the selected target aircraft. The closure indicator preferably includes a plus sign if the Own Ship aircraft is closing in on the selected target aircraft. Similarly, the closure indicator preferably includes a minus sign if the Own Ship aircraft is receding from the selected target aircraft.

In a preferred embodiment of the invention, if the rate of closure between the selected target aircraft and the Own Ship aircraft is within a predetermined range of values, the closure indicator also comprises a closing/receding indicia that further indicates whether the Own Ship aircraft is closing in on, or receding from, the selected target aircraft. In a preferred embodiment of the invention, the closing/receding indicia

comprises an upwardly-directed arrow if the Own Ship aircraft is closing in on the selected target aircraft, and a downwardly-directed arrow if the Own Ship aircraft is receding from the selected target aircraft.

More particularly, the system is preferably configured to display, at least in part in response to the closure rate being above a predetermined upper threshold value, a closure indicator that includes a closing/receding indicia that indicates that the Own Ship aircraft is closing in on the selected target aircraft. Similarly, the system is also preferably configured to display, at least in part in response to the closure rate being below a predetermined lower threshold value, a closure indicator that includes a closing/receding indicia that indicates that the Own Ship aircraft is receding from the selected target aircraft. Furthermore, in this embodiment of the invention, the system is configured to display a closure indicator that includes no closing/receding indicia if the closure rate is both: (1) equal to or above the predetermined lower threshold value; and (2) equal to or below the predetermined upper threshold value.

In a preferred embodiment of the invention, if the closure rate is above a predetermined upper threshold value, the system displays the closure indicator above a symbol representing the Own Ship aircraft. Similarly, if the closure rate is below a predetermined lower threshold value, the system displays the closure indicator below a symbol representing the Own Ship aircraft. In this embodiment of the invention, the system is configured to display the closure indicator to one side of a symbol representing the Own Ship aircraft if the closure rate is both: (1) equal to or above the predetermined lower threshold value; and (2) equal to or below the predetermined upper threshold value.

In a preferred embodiment of the invention, the predetermined upper threshold value is about 5 knots and the predetermined lower threshold value is about -5 knots. The system is preferably configured to allow a user to modify either the predetermined upper threshold value, the predetermined lower threshold value, or both the predetermined upper threshold value and the predetermined lower threshold value to accommodate current flying conditions.

In an alternative embodiment of the invention, the system is configured to only display a rate of closure on the display screen if the rate of closure between the selected target aircraft and the Own Ship aircraft is within a predetermined range of values. In

this embodiment of the invention, the system is configured to display a closure indicator in response, at least in part, to the closure rate being above a predetermined upper threshold value. Furthermore, the system is also preferably configured to display a closure indicator in response, at least in part, to the closure rate being below a predetermined lower threshold value. In this embodiment of the invention, the system is further configured to display no closure indicator on the system's display screen if the closure rate is both: (1) equal to or above the predetermined lower threshold value; and (2) equal to or below the predetermined upper threshold value.

BRIEF DESCRIPTION OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a block diagram of an aircraft surveillance system according to a preferred embodiment of the invention.

FIG. 2 is a pictorial view of a CDTI display showing a closure indicator that is displayed by an aircraft surveillance system according to a preferred embodiment of the invention when the Own Ship aircraft is closing in on a selected target aircraft at a rate of 40 knots.

FIG. 3 is a pictorial view of a CDTI display showing a closure indicator that is displayed by an aircraft surveillance system according to a preferred embodiment of the invention when the Own Ship aircraft is receding from a selected target aircraft at a rate of 60 knots.

FIG. 4 is a pictorial view of a CDTI display showing a closure indicator that is displayed by an aircraft surveillance system according to a preferred embodiment of the invention when the Own Ship aircraft is receding from a selected target aircraft at a rate of 4 knots.

FIG. 5 is a pictorial view of a keypad used in an aircraft surveillance system according to a preferred embodiment of the invention.

FIG. 6 is a graphically depicted top view of a monitoring zone according to a preferred embodiment of the invention in an example in which there is no wind so that the heading and track of the Own Ship aircraft are the same.

FIG. 7 is a graphical depiction of an example in which a system according to a preferred embodiment of the invention only displays a closure indicator on the CDTI display screen if the selected target aircraft's track is within a variation of 20 degrees of the Own Ship aircraft's track.

FIGS. 8A and 8B depict a flowchart that generally describes the logical operation of a closure indicator display module according to the current invention.

FIG. 9 is a graphical depiction that is useful in demonstrating the method used by the system to determine, based on the track and position of a currently-selected target aircraft, whether to display a closure indicator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will now be described in greater detail with reference to the accompanying drawings, which depict various preferred embodiments of the invention. Many modifications and other embodiments of the invention will come to mind to an individual who is skilled in the pertinent art as that individual reviews the description below and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and other embodiments are intended to be included within the scope of the invention. Although specific terms are employed in this description, they are used in a generic and descriptive sense only and not for purposes of limitation. Like numbers refer to like elements throughout.

As will be appreciated by one skilled in the art, the present invention may be embodied as a method, a data processing system, or a computer program product. Accordingly, the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. Furthermore, the present invention may take the form of a computer program product on a computer-readable storage medium having computer-readable program code means embodied in the storage medium. Any suitable computer-readable storage medium may be utilized including hard disks, CD-ROMs, optical storage devices, or magnetic storage devices.

The present invention is described below with reference to block diagrams and flowchart illustrations of methods, apparatuses (i.e., systems) and computer program products according to an embodiment of the invention. It will be understood that each block of the block diagrams and flowchart illustrations, and combinations of blocks in the block diagrams and flowchart illustrations, respectively, can be implemented by computer program instructions. These computer program instructions may be loaded onto a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions which execute on the computer or other programmable data processing apparatus create means for implementing the functions specified in the flowchart block or blocks.

These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instruction means that implement the function specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions that execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block or blocks.

Accordingly, blocks of the block diagrams and flowchart illustrations support combinations of means for performing the specified functions, combinations of steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flowchart illustrations, and combinations of blocks in the block diagrams and flowchart illustrations, can be implemented by special purpose hardware-based computer systems that perform the specified functions or steps, or combinations of special purpose hardware and computer instructions.

I. System Architecture

FIG. 1 shows a block diagram of an exemplary embodiment of an aircraft surveillance system **50** according to a preferred embodiment of the invention. As will be understood by one skilled in the relevant technical field, the aircraft surveillance system **50** is preferably configured for use within the cockpit of the aircraft for which the surveillance system is being used (i.e. the "Own Ship" aircraft). However, in alternative embodiments of the invention, the aircraft surveillance system **50** may be configured to operate in a location that is remote from the Own Ship aircraft. For example, the aircraft surveillance system **50** may be positioned at a ground station, and may be configured to transmit information for display on a display screen within the cockpit of the Own Ship aircraft.

The aircraft surveillance system **50** includes a processor **60** that communicates with other elements within the aircraft surveillance system **50** via a system interface or bus **61**. Also included in the aircraft surveillance system **50** is a display device/input device **64** for receiving and displaying data. This display device/input device **64** may be, for example, a keypad (such as the keypad **500** shown in Figure 5) or pointing device that is used in combination with a display screen. The aircraft surveillance system **50** further includes memory **66**, which preferably includes both read only memory (ROM) **65** and random access memory (RAM) **67**. The server's ROM **65** is used to store a basic input/output system **26** (BIOS), containing the basic routines that help to transfer information between elements within the aircraft surveillance system **50**.

In addition, the aircraft surveillance system **50** includes at least one storage device **63**, such as a hard disk drive, a floppy disk drive, a CD-ROM drive, or optical disk drive, for storing information on various computer-readable media, such as a hard disk, a removable magnetic disk, or a CD-ROM disk. As will be appreciated by one of ordinary skill in the art, each of these storage devices **63** is connected to the system bus **61** by an appropriate interface. The storage devices **63** and their associated computer-readable media provide nonvolatile storage for the aircraft surveillance system **50**. It is important to note that the computer-readable media described above could be replaced by any other type of computer-readable media known in the art. Such media include, for example, magnetic cassettes, flash memory cards, digital video disks, and Bernoulli cartridges.

A number of program modules may be stored by the various storage devices and within RAM **67**. Such program modules include an operating system **80**, and a closure indicator display module **100**. The closure indicator display module **100** controls certain aspects of the operation of the aircraft surveillance system **50**, as is described in more detail below, with the assistance of the processor **60** and an operating system **80**.

Also located within the aircraft surveillance system **50** is a system interface **74**, for interfacing and communicating with other elements of the aircraft's navigational system. It will be appreciated by one of ordinary skill in the art that one or more of the aircraft surveillance system's components may be located geographically remotely from other aircraft surveillance system **50** components. Furthermore, one or more of the components may be combined, and additional components performing functions described herein may be included in the aircraft surveillance system **50**.

II. System Overview

A system according to a preferred embodiment of the present invention includes a CDTI display for graphically displaying traffic information to a pilot within the cockpit of an aircraft. Figures 2, 3, and 4 are pictorial representations of such a CDTI display. As may be understood from these figures, a typical CDTI display **200, 300, 400** includes a graphical depiction of an Own Ship aircraft **202, 302, 402** and various aircraft (such as aircraft **205, 305, 405**) that are flying in the general vicinity of the Own Ship aircraft **202, 302, 402**. Such aircraft are generally referred to as "target" aircraft **205, 305, 405**. The CDTI further includes a keypad, such as the keypad **500** shown in Figure 5, for allowing a pilot of the Own Ship aircraft **202, 302, 402** to change various display parameters on the CDTI display. This keypad **500** preferably includes a TGT button **520** that is configured to allow a user to turn a "target selection mode" on or off. When the target selection mode is turned on, the user may use the T↑ button **521** and the T↓ button **522** to select a current target aircraft by toggling between the various target aircraft **205, 305, 405**. The T↑ button **521** selects, as the next selected target aircraft, the next farthest target aircraft from the Own Ship aircraft **202, 302, 402**. Similarly, the T↓ button **522**, selects, as the next selected target aircraft, the next nearest target aircraft from the Own Ship aircraft **202, 302, 402**.

As shown in Figure 2, once the pilot designates a particular aircraft as the selected target aircraft, the system visually distinguishes the selected aircraft **205** from other target aircraft by displaying a thin line **207** around the outer perimeter of the symbol representing the selected target aircraft **205**, and by changing the color of the symbol representing the selected target aircraft **205**. The system also preferably displays additional information regarding the selected target aircraft **205**. For example, as shown in Figure 2, the system displays the ground speed **215** of the selected target aircraft in the lower left hand corner of the CDTI display screen **200**.

The present invention provides an enhanced CDTI display that alerts pilots to changes in the relative positions, tracks, and movement of the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405**. In a preferred embodiment of the invention, when the relative positions, tracks, and rates of closure of the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** meet certain conditions, the system displays, in an easily-readable, graphical manner, an indication of closure **220, 320, 420** between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405**. A graphic closure indicator according to a preferred embodiment of the invention is described in greater detail below.

III. Display of Closure Indicator

In a preferred embodiment of the invention, the system is configured to display a closure indicator **220, 320, 420** on the display screen **200, 300, 400** of an aircraft surveillance system (such as a CDTI) when certain conditions are satisfied. As may be understood from Figures 2 and 3, the system preferably displays the closure indicator **220, 320, 420** adjacent a symbol that represents the Own Ship aircraft **202, 302, 402**.

In a preferred embodiment of the invention, the closure indicator **220, 320, 420** includes a closure rate indicator **224, 324, 424** that indicates the current rate at which the Own Ship aircraft **202, 302, 402** is closing in on, or receding from, the selected target aircraft **205, 305, 405**. This closure rate indicator **224, 324, 424** preferably comprises an alphanumeric closure rate value **226, 326, 426** and a positive or negative symbol **228, 328, 428** to indicate whether the Own Ship aircraft **202, 302, 402** is closing in on, or receding from, the selected target aircraft **205, 305, 405**. In this embodiment of the

invention, the closure rate indicator **224, 324, 424** includes a positive sign immediately to the left of the alphanumeric closure rate value **226, 326, 426** if the Own Ship aircraft **202, 302** is closing in on the selected target aircraft **205, 305, 405**. By the same token, the closure rate indicator **224** includes a negative sign immediately to the left of the alphanumeric closure rate value **226, 326, 426** if the Own Ship aircraft **202, 302, 402** is receding from the selected target aircraft **205, 305, 405**. In a preferred embodiment of the invention, the closure rate indicator **224, 324, 424** displays the closure rate in knots.

In a preferred embodiment of the invention, the closure indicator **220, 320, 420** may also comprise a closing/receding indicia **222, 322** that further indicates whether the Own Ship aircraft **202, 302, 402** is closing in on, or receding from, the selected target aircraft **205, 305, 405**. This closing/receding indicia **222, 322** is preferably a directional symbol that indicates by its orientation whether the Own Ship aircraft **202, 302, 402** is closing in on, or receding from, the selected target aircraft **205, 305, 405**. In a preferred embodiment of the invention, the closing/receding indicia **222, 322** is displayed (as shown in Figure 2) as an upwardly-directed arrow if the Own Ship aircraft **202, 302, 402** is closing in on the selected target aircraft **205, 305, 405**. Similarly, in this embodiment of the invention, the closing/receding indicia **222, 322** is displayed as a downwardly-directed arrow (as shown in Figure 3) if the Own Ship aircraft **202, 302, 402** is receding from the selected target aircraft **205, 305, 405**.

The system is preferably configured so that the closure indicator **220, 320, 420** only includes a closing/receding indicia **222, 322** if the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is within a pre-determined range. In a preferred embodiment of the invention, the closure indicator **220, 320, 420** only includes a closing/receding indicia **222, 322** if the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is: (1) greater than a pre-determined upper threshold value; or (2) less than a pre-determined lower threshold value. Otherwise, as shown in Figure 4, the system preferably displays a closure indicator **220, 320, 420** that does not include a closing/receding indicia **222, 322**. In a preferred embodiment of the invention, the pre-determined upper threshold value is 5 knots, and the pre-determined lower threshold value is –5 knots.

It should be understood that the pre-determined range (or ranges) of closure rates for which the closure indicator **220, 330** will include a closing/receding indicia **222, 322** can be defined according to any desired set of display rules. For example, the system may be configured so that the closure indicator **220, 330** will only include a closing/receding indicia **222, 322** if the current rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is greater than a pre-determined upper threshold value. Alternatively, the system may be configured so that the closure indicator **220, 330** will only include a closing/receding indicia **222, 322** if the current rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is less than a pre-determined lower threshold value. In an alternative embodiment of the invention, the system may be configured so that the closure indicator **220, 330** always includes a closing/receding indicia **222, 322**.

In a preferred embodiment of the invention, the system is configured to allow a pilot, or other user, to define (preferably while the aircraft is in flight) the pre-determined range (or ranges) of closure rates for which the closure indicator **220, 330** will include a closing/receding indicia **222, 322**. For example, the system may allow a pilot or other user to modify the pre-determined upper threshold value and/or the pre-determined lower threshold value as desired. This feature is advantageous because it allows a pilot to set the pre-determined range for closing/receding indicia display in response to current flying conditions.

To enhance the readability of the display screen **200, 300, 400**, the system is preferably configured to position the closure indicator **220, 320, 420** on the display screen **200, 300, 400** in response to the closure rate between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** satisfying certain criteria. For example, in a preferred embodiment of the invention, the system is configured to display the closure indicator **220, 320, 420** immediately adjacent the front end **203, 303** of the symbol representing the Own Ship aircraft **202, 302, 402** (as shown in Figure 2) if the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is greater than the pre-determined upper threshold value. In this embodiment of the invention, the system is further configured to display the closure indicator **220, 320, 420** immediately adjacent the rear end **204, 304** of the Own Ship

symbol **202, 302, 402** (as shown in Figure 3) if the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is less than the predetermined lower threshold value. The system is further preferably configured to display the closure indicator **220, 320** to one side of a symbol representing the Own Ship aircraft **202, 302, 402** (as shown in Figure 4) if the closure rate is both: (1) equal to or above the predetermined lower threshold value; and (2) equal to or below the predetermined upper threshold value.

Figures 2, 3, and 4 provide two examples of closure indicators **220, 320, 420** according to a preferred embodiment of the invention. Figure 2 depicts a situation in which an Own Ship aircraft **202** is closing in on the selected target aircraft **205**, at a rate of 40 knots. As shown in this figure, because the Own Ship aircraft **202** is closing in on the selected target aircraft **205**, the closure indicator **220** includes a plus sign **228** immediately to the left of the closure rate indicator **226**. Furthermore, because the Own Ship aircraft **202** is closing in on the selected target aircraft **205** at a rate that is greater than a predetermined upper threshold value of 5 knots, the closure indicator **220** includes an upwardly-directed arrow **222** and the closure indicator **220** is positioned immediately adjacent a front end **203** of the symbol representing the Own Ship aircraft **202**.

Figure 3 depicts a situation in which an Own Ship aircraft **302** is receding from the selected target aircraft **305** at a rate of 60 knots. As shown in this figure, because the Own Ship aircraft **302** is receding from the selected target aircraft **305**, the closure indicator **320** includes a minus sign **328** immediately to the left of the closure rate indicator **326**. Furthermore, because the Own Ship aircraft **302** is receding from the selected target aircraft **305** at a rate that is less than a predetermined lower threshold value of -5 knots, the closure indicator **320** includes a downwardly-directed arrow **322** and the closure indicator **320** is positioned immediately adjacent a rear end **303** of the symbol representing the Own Ship aircraft **302**.

Figure 4 depicts a situation in which an Own Ship aircraft **402** is receding from the selected target aircraft **405** at a rate of 4 knots. As shown in this figure, because the Own Ship aircraft **402** is receding from the selected target aircraft **405**, the closure indicator **420** includes a minus sign **428** immediately to the left of the closure rate indicator **426**. Furthermore, because the closure rate between the Own Ship aircraft **402**

and the selected target aircraft **405** is less than a predetermined upper threshold value of 5 knots, and greater than a predetermined lower threshold value of –5 knots, the closure indicator **420** includes no closing/receding indicia **222, 322** and the closure indicator **420** is positioned to one side of the symbol representing the Own Ship aircraft **402**.

It should be understood that the preferred embodiment of the invention described above conveys, in three different ways, whether the Own Ship aircraft **202, 302, 402** is closing in on or receding from the selected target aircraft **205, 305, 405**. More particularly, the system conveys this information via: (1) a plus or minus sign **228, 328, 428** displayed immediately to the left of the alphanumeric closure rate value **226, 326, 426**; (2) the orientation of the closing/receding indicia **222, 322**; and (3) the position of the closure indicator **220, 320** relative to the Own Ship symbol **202, 302, 402**.

It should be understood that alternative embodiments of the invention may be configured to use any two of the above methods to indicate wither the Own Ship aircraft is closing in on, or receding from, the selected target aircraft. For example, the system may be configured to indicate whether the Own Ship is closing in on, or receding from the selected target aircraft by displaying a positive or negative sign **228, 328, 428** immediately to the left of the alphanumeric closure rate value **226, 326, 426**, and by displaying a properly-oriented closing/receding indicia **222, 322**, but not by varying the position of the closure indicator **220, 320** relative to the Own Ship symbol **202, 302, 402**. Similarly, the system may be configured to display a positive or negative sign **228, 328, 428** immediately to the left of the alphanumeric closure rate value **226, 326, 426** and to vary the position of the closure indicator **220, 320** relative to the Own Ship symbol **202, 302, 402** according to whether the Own Ship aircraft is closing in on or receding from the selected target aircraft **205, 305, 405**, but not to include a closing/receding indicia **222, 322** for indicating the relative movement of the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405**.

By the same token, the system may be configured to display only one of the three indicators of closing/receding discussed above. For example, in an alternative embodiment of the invention, the system may be configured to vary the position of the closure indicator **320** relative to the Own Ship symbol **202, 302, 402** according to whether the Own Ship aircraft **202, 302, 402** is closing in on or receding from the

selected target aircraft **205, 305, 405**, but not to include a positive or negative sign **228, 328, 428** or a closing/receding indicia **222, 322** to indicate the relative movement of the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405**.

IV. Conditions For Closure Indicator Display

As noted above, in a preferred embodiment of the invention, the system only displays the closure indicator **220, 320, 420** on the display screen **200, 300, 400** under certain pre-determined conditions. More specifically, the system preferably only displays the closure indicator **220, 320, 420** if: (1) the selected target aircraft **205, 305, 405** is within a pre-determined monitoring zone; and (2) the track of the selected target aircraft **205, 305, 405** is within a specified variance angle of the track of the Own Ship aircraft **202, 302, 402**. In an alternative embodiment of the invention, the system will only display a closure indicator **223, 320, 420** if the above two requirements are satisfied and: (3) the closure rate between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is within a certain pre-determined range. These conditions are discussed in greater detail below.

A. Requirement 1 – The Selected Target Aircraft is within a Pre-determined Monitoring Zone.

As noted above, the system preferably only displays a closure indicator **220, 320, 420** on the display screen **200, 300, 400** if the selected target aircraft **205, 305, 405** is within a pre-determined monitoring zone **604, 904**. In a preferred embodiment of the invention depicted in Figure 6, this monitoring zone **604** is a three-dimensional, substantially cone-shaped segment of airspace having an axis **610** that is substantially co-linear with the track **615** of the Own Ship aircraft **602**. The apex **630** of this cone is preferably immediately adjacent a front end **620** of the Own Ship aircraft **602** and extends outwardly from the front of the Own Ship aircraft **602**. In a preferred embodiment of the invention, the cone-shaped segment of airspace is in the form of a right cone and the vertex angle **635** of the cone-shaped segment of airspace is about 40 degrees. (**Note:** For the sake of simplifying Figures 6, 7, and 9, these figures each depict examples in which there is no wind so that the track of the Own Ship aircraft **602, 702, 902** is the same as the

heading of the Own Ship aircraft **602**, **702**, **902**, and so that the track of each target aircraft is the same as its heading.)

As will be understood by one skilled in the art, while the monitoring zone **604** is preferably a cone-shaped segment of airspace extending outwardly from the front portion **620** of the Own Ship aircraft **602**, the monitoring zone **604** can be in any other shape or orientation. For example, the monitoring zone **604** could be in the form of an elongated cylinder that has a major axis that is substantially co-linear with the major axis **615** of the Own Ship aircraft **602**. Alternatively, the monitoring zone **604** could be in the form of a cone that is not a right cone, or a right cone that has its apex adjacent the rear end **625** of the Own Ship aircraft **602** rather than the front end **620** of the Own Ship aircraft **602**. In a preferred embodiment of the invention, to accommodate current flying conditions, the system is configured to allow a pilot or other user to select a current monitoring zone from several different monitoring zones having different shapes and orientations. In a further preferred embodiment of the invention, the system is configured to allow a user to modify at least one boundary of the current monitoring zone **604** as desired. For example, the system may allow a user to specify a different apex angle **635** for current a cone-shaped monitoring zone. This, in turn, would redefine the boundaries of the current monitoring zone **604**.

B. Requirement 2 – The Selected Target Aircraft's Track is Within a Selected Variation Angle of the Own Ship Aircraft's Track

As noted above, the system preferably only displays a closure indicator **220, 320, 420** on the CDTI display screen **200, 300, 400** if the selected target aircraft's track is within a selected variation angle of the Own Ship aircraft's track. To determine the variation angle between the selected target aircraft's track and the track of the Own Ship aircraft **202, 302, 402**, the system first determines the two-dimensional horizontal track of the Own Ship aircraft **202, 302, 402**. Next, the system determines the two-dimensional horizontal track of the selected target aircraft **205, 305, 405**. The system then determines a "variation angle" between the track of the Own Ship aircraft **202, 302, 402** and the track of the selected target aircraft **205, 305, 405**. This variation angle is simply the angular difference between the track of the selected target aircraft **205, 305, 405** and the track of

the Own Ship aircraft **202, 302, 402**. If this angle is greater than a pre-determined threshold variation angle, the system does not display a closure indicator **220, 320, 420** on the display screen **200, 300, 400**.

Figure 7 graphically illustrates an example in which there is no wind so that the track of the Own Ship aircraft **702** is the same as the heading of the Own Ship aircraft **702**, and so that the track of each target aircraft is the same as its heading. In this example, the system only displays a closure indicator **220, 320, 420** on the CDTI display screen **200, 300, 400** if the selected target aircraft's track is within a variation angle of 20 degrees of the Own Ship aircraft's track. More particularly, this figure depicts an Own Ship aircraft **702**, a first group of aircraft **705-730, 750-760** ("Group A") that have tracks that would not result in a closure indicator **220, 320, 420** being displayed on the Own Ship aircraft's display screen **200, 300, 400**. This figure also includes a second group of aircraft **735-745** ("Group B") that have tracks that would result in a closure indicator **220, 320, 420** being displayed on the Own Ship aircraft's display screen **200, 300, 400**.

Turning to Group A, target aircraft **705, 710, 715, 720, 725, 730, 750, 755,** and **760** have tracks that are offset from the track of the Own Ship aircraft **702** in a clockwise direction by 25 degrees, 90 degrees, 155 degrees, 205 degrees, 270 degrees, 335 degrees, 165 degrees, 180 degrees, and 195 degrees, respectively. Accordingly, the variation angle between the track of the Own Ship aircraft **702** and the tracks of target aircraft **705** and **730** is 25 degrees. Similarly, the variation angle between the track of the Own Ship aircraft **702** and the tracks of target aircraft **715, 720** is 155 degrees. By the same token, the variation angle between the track of the Own Ship aircraft **702** and the tracks of target aircraft **710, 725** is 90 degrees. Also, the variation angle between the track of Own Ship aircraft **702** and the tracks of target aircraft **750** and **760** is 165 degrees. The variation angle between the track of the Own Ship aircraft **702** and the track of target aircraft **755** is 180 degrees. Because, in this example, the system will only display a closure indicator **220, 320, 420** if the variation angle between the Own Ship aircraft **702** and the selected target aircraft is 20 degrees or less, the system will not display a closure indicator **220, 320, 420** if any of the aircraft in Group A (i.e. aircraft **705, 710, 715, 720, 725, 730, 750, 755, 760**) is designated as the selected target aircraft.

Focusing now on Group B, target aircraft **740, 745, 735** have tracks that are offset from the track of the Own Ship aircraft **702** in a clockwise direction by 0 degrees, 15 degrees, and 345 degrees, respectively. Accordingly, the variation angle between the track of the Own Ship aircraft **702** and the tracks of target aircraft **745** and **735** is 15 degrees. Similarly, the variation angle between the track of the Own Ship aircraft **702** and the track of target aircraft **740** is 0 degrees. Because, in this example, the system will display a closure indicator **220, 320, 420** if the selected target aircraft's track diverges from the track of the Own Ship aircraft by a threshold variation angle of 20 degrees or less, the system will display a closure indicator **220, 320, 420** if any of the aircraft in Group B is designated as the selected target aircraft.

While, in a preferred embodiment of the invention, the threshold variation angle is 20 degrees, the system may be configured to have a larger or smaller variation angle. In a preferred embodiment of the invention, the system is configured to allow a pilot or other user to modify the variation angle during flight to accommodate current flying conditions or user preferences.

C. Requirement 3 – The Rate of Closure is within a Pre-Determined Range.

As noted above, in an alternative embodiment of the invention, the system preferably only displays a closure indicator **220, 320, 420** on the CDTI display screen **200, 300, 400** if the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is within a pre-determined range. More specifically, in this embodiment of the invention, the system only displays a closure indicator **220, 320, 420** if the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is either: (1) greater than a pre-determined upper threshold value; or (2) less than a pre-determined lower threshold value. Otherwise, the system does not display a closure indicator **220, 320, 420** on the Own Ship Aircraft's display screen. As noted above, in a preferred embodiment of the invention, the pre-determined upper threshold value is 5 knots, and the pre-determined lower threshold value is –5 knots.

It should be understood that the pre-determined range (or ranges) of closure rates for which the system will display a closure indicator **220, 320, 420** can be defined

according to any desired set of display rules. For example, the system may be set to only display a closure indicator **220, 320, 420** if the current rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is greater than a pre-determined upper threshold value. Alternatively, the system may be set to only display a closure indicator **220, 320, 420** if the current rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is less than a pre-determined lower threshold value. In a preferred embodiment of the invention, the system is configured to allow a pilot or other user define (preferably while the aircraft is in flight) the pre-determined range (or ranges) of closure rates for which the system will display a closure indicator **220, 320, 420**. This feature is advantageous because it allows a pilot to set the pre-determined range for closure rate display in response to current flying conditions.

V. Alternative Embodiment Requiring Different Combinations of the above Requirements for Closure Indicator Display

In a preferred embodiment of the invention, the system is configured to display a closure indicator **220, 320, 420** in response to Requirements 1 and 2, above, being satisfied. However, alternative embodiments of the invention may be configured to display a closure indicator **220, 320, 420** in response to any pre-determined combination of two or more of Requirements 1-3 being satisfied. For example, the system may be configured to display a closure indicator **220, 320, 420** only if: (1) the selected target aircraft **205, 305, 405** is within a pre-determined monitoring zone; (2) the selected target aircraft's track is within a selected variation angle of the Own Ship aircraft's track; and (3) the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is within a pre-determined range. Alternatively, the system may be configured to display a closure indicator **220, 320, 420** only if the selected target aircraft **205, 305, 405** is within a pre-determined monitoring zone, and the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is within a pre-determined range. As a further alternative, the system may be configured to display a closure indicator **220, 320, 420** only if the selected target aircraft's track is within a selected variation angle of the Own Ship aircraft's track, and

the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** is within a pre-determined range.

Furthermore, the system may be configured to display a closure indicator **220, 320, 420** in response to only one of Requirements 1-3, above, being satisfied. For example, the system may be configured to display a closure indicator **220, 320, 420** in response to the selected target aircraft **205, 305, 405** being within a pre-determined monitoring zone. Similarly, the system may be configured to display a closure indicator **220, 320, 420** in response to a track of the selected target aircraft **205, 305, 405** being within a pre-determined variation angle of the track of the Own Ship aircraft **202, 302, 402**. By the same token, the system may be configured to display a closure indicator **220, 320, 420** in response to the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** being within a pre-determined range. In a further embodiment of the invention, the system is configured to constantly display a closure indicator **220, 320, 420** while the Own Ship aircraft **202, 302, 402** is in flight.

In a preferred embodiment of the invention, the system is configured to allow a pilot or other user to modify the conditions under which the system will display a closure indicator **220, 320, 420**. The system preferably allows this to be done while the aircraft is in flight. For example, in a preferred embodiment of the invention, the system may allow a user to re-configure the system during flight from a first configuration to a second configuration. In the first configuration, the system may be configured, for example, to display a closure indicator **220, 320, 420** in response to the selected target aircraft's track being within a selected variation angle of the Own Ship aircraft's track. In the second configuration, the system may be configured to display a closure indicator **220, 320, 420** in response to: (1) the selected target aircraft's track being within a selected variation angle of the Own Ship aircraft's track; and (2) the rate of closure between the Own Ship aircraft **202, 302, 402** and the selected target aircraft **205, 305, 405** being within a pre-determined range. This functionality is advantageous because it allows pilots to configure the system as appropriate for current flying conditions.

VI. Automatic Removal of the Closure Indicator from the Display Screen

In a preferred embodiment of the invention, the system removes a closure indicator **220, 320, 420** from display on the Own Ship aircraft's display screen **200, 300, 400** in response to the Own Ship aircraft **202, 302, 402** landing. The system also preferably removes a closure indicator **220, 320, 420** from display on the Own Ship Aircraft's display screen **200, 300, 400** in response to the selected target aircraft **205, 305, 405** landing. This functionality is useful because an indication of closure is no longer necessary once either the Own Ship aircraft **202, 302, 402** or the selected target aircraft **205, 305, 405** has landed. In an alternative embodiment of the invention, the system removes a closure indicator **220, 320, 420** from display on the Own Ship Aircraft's display screen **200, 300, 400** in response to the selected target aircraft **205, 305, 405** landing, but does not move the closure indicator **220, 320, 420** from display in response to the Own Ship aircraft **202, 302, 402** landing. In a further alternative embodiment of the invention, the system removes a closure indicator **220, 320, 420** from display on the Own Ship aircraft's display screen **200, 300, 400** in response to the Own Ship aircraft **202, 302, 402** landing, but does not move the closure indicator **220, 320, 420** from display in response to the selected target aircraft **205, 305, 405** landing.

VII. General Operation of a Preferred Embodiment of the Invention

Figures 8A and 8B depict the general logic flow of a closure indicator display module **800** according to a preferred embodiment of the invention. When executing such a closure indicator display module **800**, the system first executes Step **810** in which the system determines whether the selected target aircraft **205, 305, 405** is within a pre-determined monitoring zone **604** as discussed above. If so, the system proceeds to Step **820**. If not, the system proceeds to Step **825**, does not display a closure indicator **220, 320, 420** on the Own Ship aircraft's display screen **200, 300, 400**, and returns to Step **810**.

At Step **820**, the system determines whether the selected target aircraft's track is within a pre-determined variation angle of the Own Ship aircraft's track. If so, the system proceeds to Step **830**. If not, the system proceeds to Step **825**, does not display a

closure indicator **220, 320, 420** on the Own Ship aircraft's display screen **200, 300, 400**, and returns to Step **810**.

At Step **830**, the system determines whether the closure rate between the selected target aircraft **205, 305, 405** and the Own Ship aircraft **202, 302, 402** is equal to or below a pre-determined upper threshold value. If so, the system proceeds to Step **850**. If not (i.e., the closure rate is above the pre-determined upper threshold value), the system executes Step **840**, where it displays a closure indicator **220, 320, 420** that includes a closing/receding indicia **222, 322**. The system displays this closure indicator **220, 320** on the Own Ship aircraft's display screen **200, 300, 400** immediately above a symbol representing the Own Ship aircraft **202, 302, 402**. After executing Step **840**, the system returns to Step **810**.

At Step **850**, the system determines whether the closure rate between the selected target aircraft **205, 305, 405** and the Own Ship aircraft **202, 302, 402** is equal to or above a predetermined lower threshold value. If so, the system proceeds to Step **870**, where it displays a closure indicator **220, 320, 420** that does not include a closing/receding indicia. The system displays this closure indicator **220, 320** on the Own Ship aircraft's display screen **200, 300, 400** to one side of a symbol representing the Own Ship aircraft **202, 302, 402**. After executing Step **870**, the system returns to Step **810**.

If the system determines, at Step **850**, that the closure rate between the selected target aircraft **205, 305, 405** and the Own Ship aircraft **202, 302, 402** is not equal to or above a predetermined lower threshold value (i.e., the closure rate is below the pre-determined lower threshold value), the system executes Step **860** where it displays a closure indicator **220, 320, 420** that includes a closing/receding indicia **222, 322**. The system displays this closure indicator **220, 320** on the Own Ship aircraft's display screen **200, 300, 400** immediately below a symbol representing the Own Ship aircraft **202, 302, 402**. After executing Step **840**, the system returns to Step **810**.

In this embodiment of the invention, the system also removes the closure indicator **220, 320, 420** from display on the Own Ship aircraft's display screen **200, 300, 400** when either the Own Ship aircraft **202, 302, 402** or the selected target aircraft **205, 305, 405** lands.

Figure 9, which graphically depicts an Own Ship aircraft **902** flying in relation to several target aircraft **940–960**, may be used to further understand the general functionality of a system according to a preferred embodiment of the invention. In this preferred embodiment of the invention, the system is configured to only display a closure indicator **220, 320, 420** if the selected target aircraft is within a pre-determined monitoring zone **904** that is defined by a cone-shaped segment of airspace having an apex angle **935** of 40 degrees, that has an apex **930** that is positioned immediately adjacent the front end **920** of the Own Ship aircraft **902**, and that extends outwardly from the front portion **920** of the Own Ship aircraft **902** so that the axis **910** of the cone-shaped segment of airspace is substantially co-linear with the major axis of the Own Ship aircraft **902**.

Furthermore, the system is configured to only display a closure indicator **220, 320, 420** on the Own Ship aircraft's display screen if the track of the selected target aircraft is within a 20 degree variation angle from the Own Ship aircraft's track. As mentioned above, this figure depicts an example in which there is no wind so that the track of the Own Ship aircraft **902** is the same as the heading of the Own Ship aircraft **902**, and so that the track of each target aircraft is the same as its heading.

In the example shown in Figure 9, the system clearly would not display a closure indicator **220, 320, 420** if aircraft **945** were the selected target aircraft because aircraft **945** is well outside of the pre-determined monitoring zone **904**. Similarly, even though aircraft **940**, **950**, and **955** may be within the pre-determined monitoring zone **904**, the system would not display a closure indicator **220, 320, 420** if any of these aircraft were designated as the selected target aircraft because the variation angle between the track of each of these aircraft and the Own Ship aircraft **902** is greater than the threshold 20 degree variation angle. More particularly, the variation angle between track of the Own Ship aircraft **902** and the track of target aircraft **955** is about 90 degrees. Similarly, the variation angle between the Own Ship aircraft between the track of the Own Ship aircraft **902** and the track of the target aircraft **950** is about 180 degrees. By the same token, the variation angle between the track of the Own Ship aircraft **902** and the track of target aircraft **940** is about 45 degrees.

As may be understood from Figure 9, the variation angle between the Own Ship aircraft **902** and target aircraft **960** is about 0 degrees. Thus, presuming that aircraft **960**

is not outside of the pre-determined monitoring zone **904** by virtue of its altitude, the system would display a closure indicator **220, 320, 420** on the Own Ship aircraft's display screen **200, 300, 400** if this aircraft were the selected target aircraft.

VIII. Conclusion

Many modifications and other embodiments of the invention will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.